$t\bar{t}H \rightarrow$ 4 leptons at ATLAS

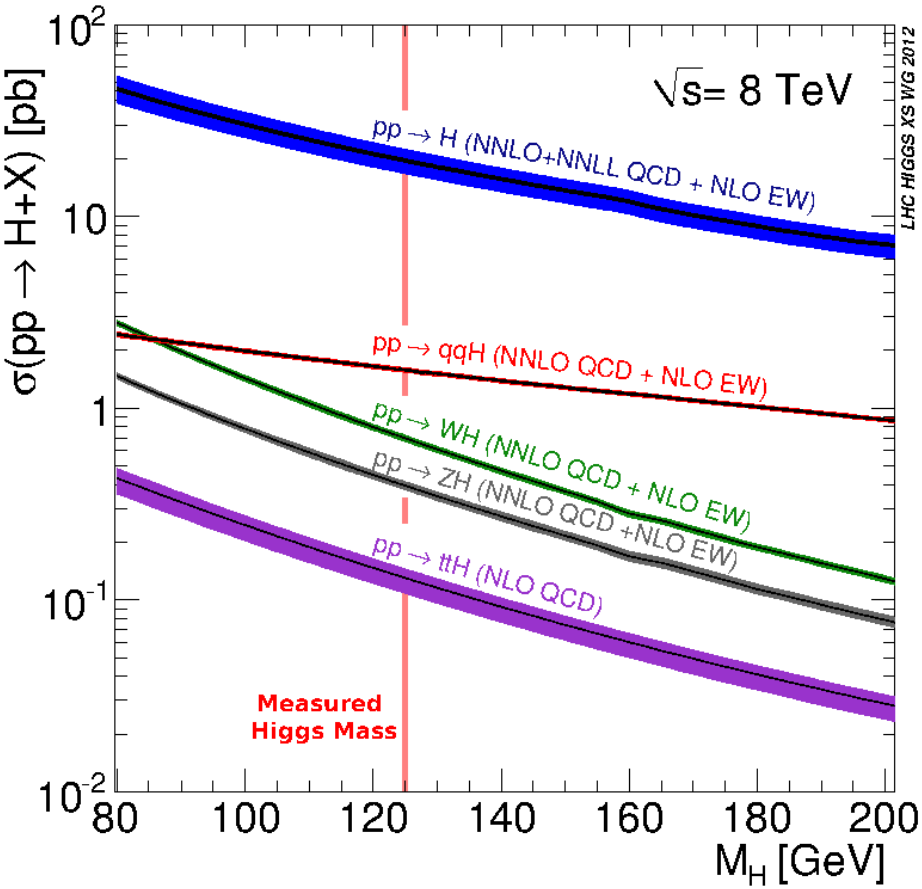
Olivia Wasalski

August 15, 2013

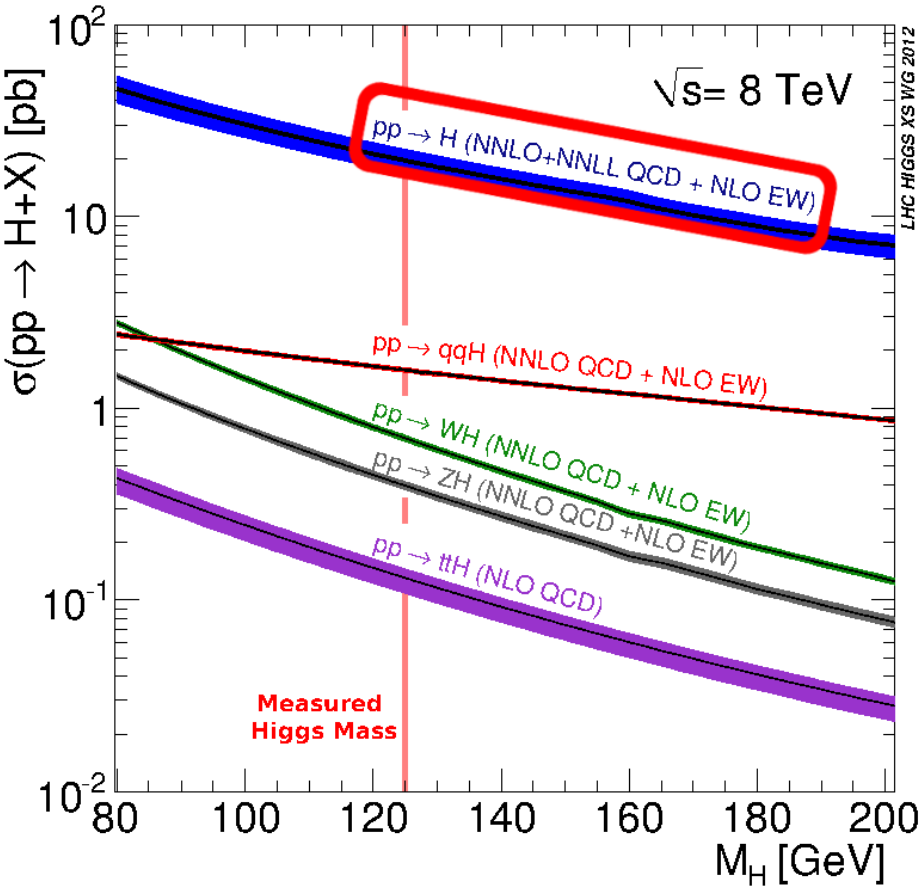
UNIVERSITY OF TORONTO

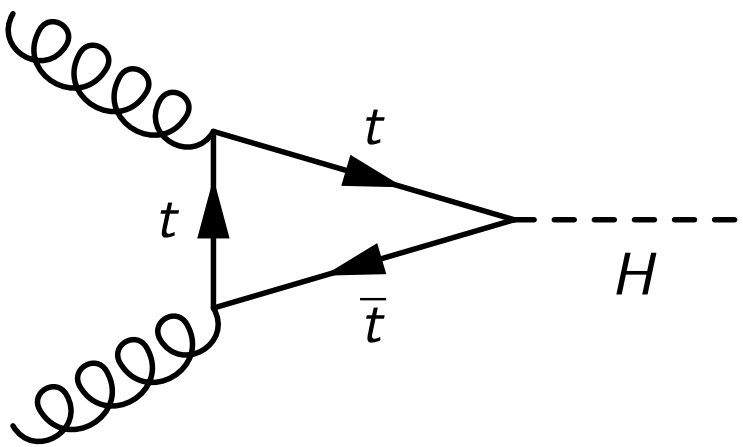
Outline

Higgs Production Mechanisms at the LHC



Higgs Production Mechanisms at the LHC

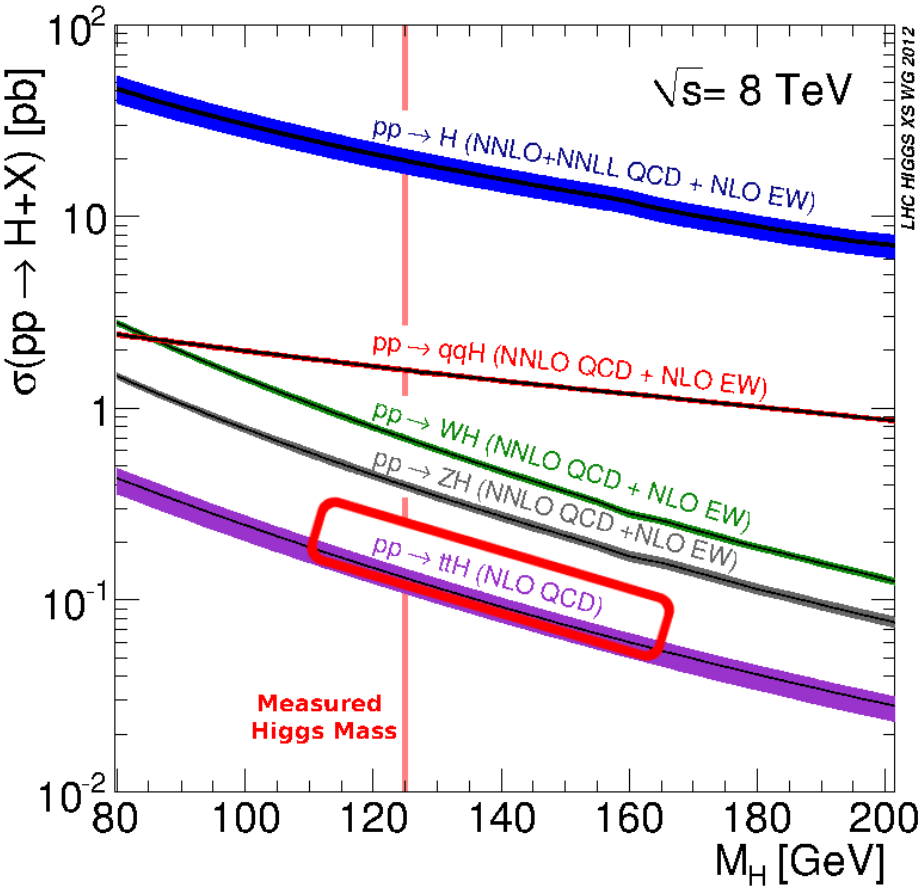


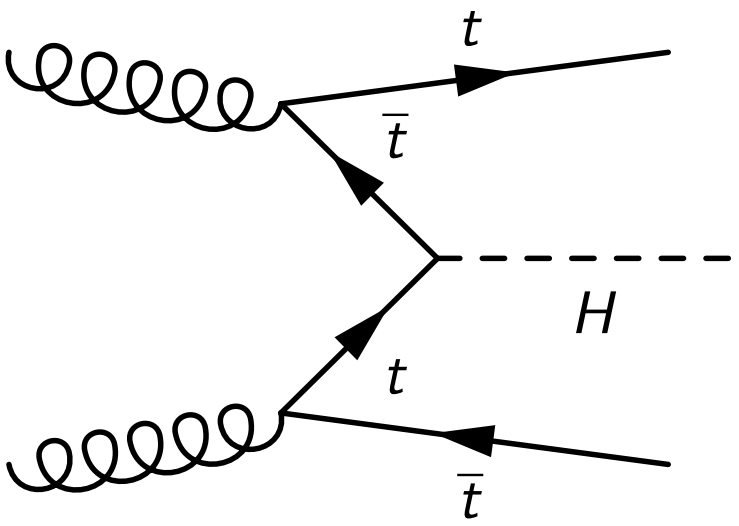


Gluon-gluon fusion

Dominant production mode

Higgs Production Mechanisms at the LHC





$t\bar{t}$ fusion

Direct access to top Yukawa coupling

$t\bar{t}H$ Analysis Channels at ATLAS

$t\bar{t}H \rightarrow b\bar{b}$:

- Fully hadronic: 4 b-jets + 4 additional jets
- 1 charged lepton + 4 b-jets + 2 additional jets
- 2 opposite sign charged leptons + 4 b-jets

$t\bar{t}H \rightarrow \gamma\gamma$:

- 2 photons + 2 b-jets + 4 additional jets
- 2 photons + 2 b-jets + 1-2 charged leptons + 0-1 additional jets

$t\bar{t}H \rightarrow$ multileptons:

- Includes $H \rightarrow W^+W^-$, $H \rightarrow \tau^+\tau^-$ and $H \rightarrow ZZ$ decay modes
- 2 same sign charged leptons + 2 b-jets + 4 additional jets
- 3 charged leptons + 2 b-jets + 2 additional jets
- 4 charged leptons + 2 b-jets

$t\bar{t}H$ Analysis Channels at ATLAS

$t\bar{t}H \rightarrow b\bar{b}$:

- Fully hadronic: 4 b-jets + 4 additional jets
- 1 charged lepton + 4 b-jets + 2 additional jets
- 2 opposite sign charged leptons + 4 b-jets

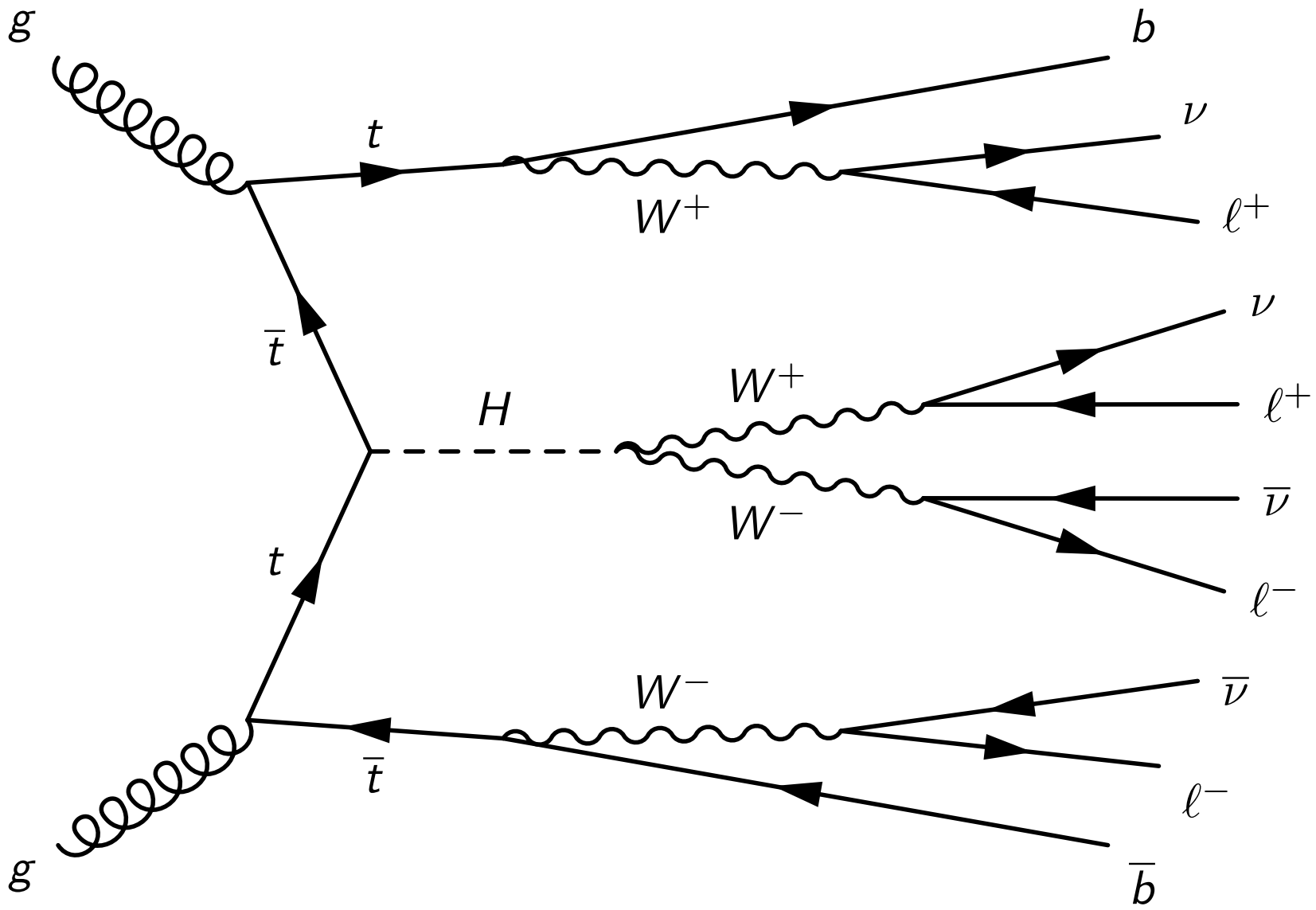
$t\bar{t}H \rightarrow \gamma\gamma$:

- 2 photons + 2 b-jets + 4 additional jets
- 2 photons + 2 b-jets + 1-2 charged leptons + 0-1 additional jets

$t\bar{t}H \rightarrow$ multileptons:

- Includes $H \rightarrow W^+W^-$, $H \rightarrow \tau^+\tau^-$ and $H \rightarrow ZZ$ decay modes
- 2 same sign charged leptons + 2 b-jets + 4 additional jets
- 3 charged leptons + 2 b-jets + 2 additional jets
- 4 charged leptons + 2 b-jets $\leftarrow$ **very clean channel, but low BR**

4 Lepton Event Signature



4 Lepton Backgrounds

Two major backgrounds for this channel:

$ZZ^* \rightarrow 4l$

- Reducible
- Z veto
- No b-jets
- Different kinematics
- Relatively well understood - major background for $H \rightarrow ZZ^* \rightarrow 4l$

$ttZ/\gamma^* \rightarrow 4l$

- ttZ is reducible with a Z veto
- $tt\gamma^*$ is irreducible
- Huge theoretical cross section uncertainty
- No published experimental cross section measurement

Additional backgrounds considered:

- ttW, ttWW, ttbb, ttcc, tt, WZ, Wγ^*

4 Lepton Analysis Strategy

Up to now these are MC studies (First CRs unblinded last week)

Plan to use data driven techniques as much as possible

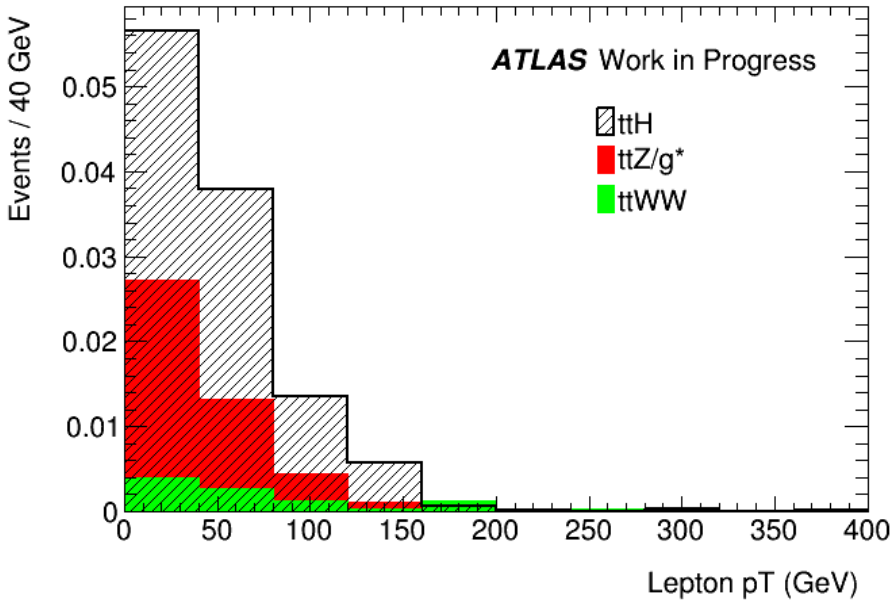
Counting experiment with multiple SRs

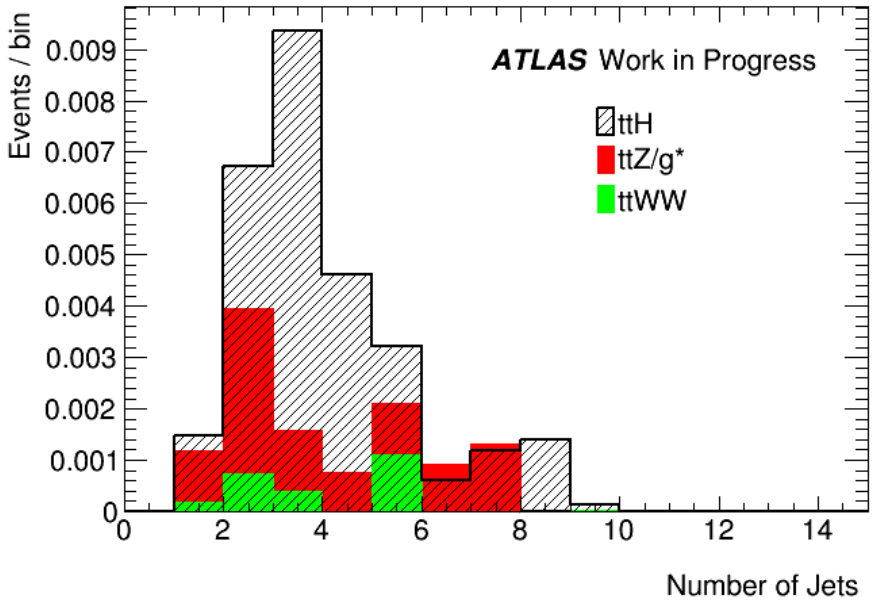
- $Z \to \ell^+\ell^-$ is the largest SM source of mutileptonic final states
- Can split signal regions into how many Zs could possibly create the final state leptons

4 lepton signal regions:

- Z depleted: $e^{\pm}e^{\pm}\mu^{\mp}\mu^{\mp}$
- Z enriched: $eee\mu$ and $e\mu\mu\mu$
- ZZ enriched: $eeee$, $\mu\mu\mu\mu$ and $e^{\pm}e^{\mp}\mu^{\pm}\mu^{\mp}$

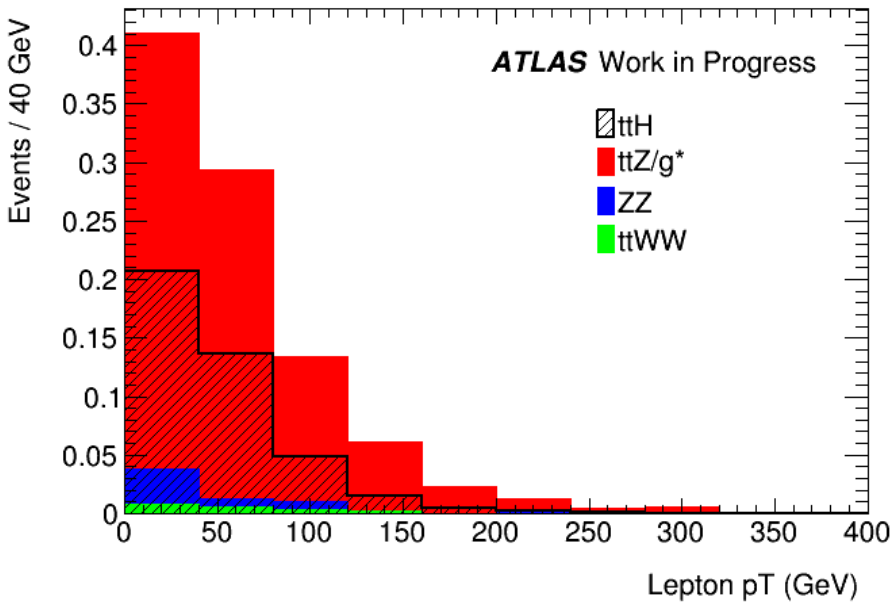
Z Depleted: $e^{\pm}e^{\pm}\mu^{\mp}\mu^{\mp}$

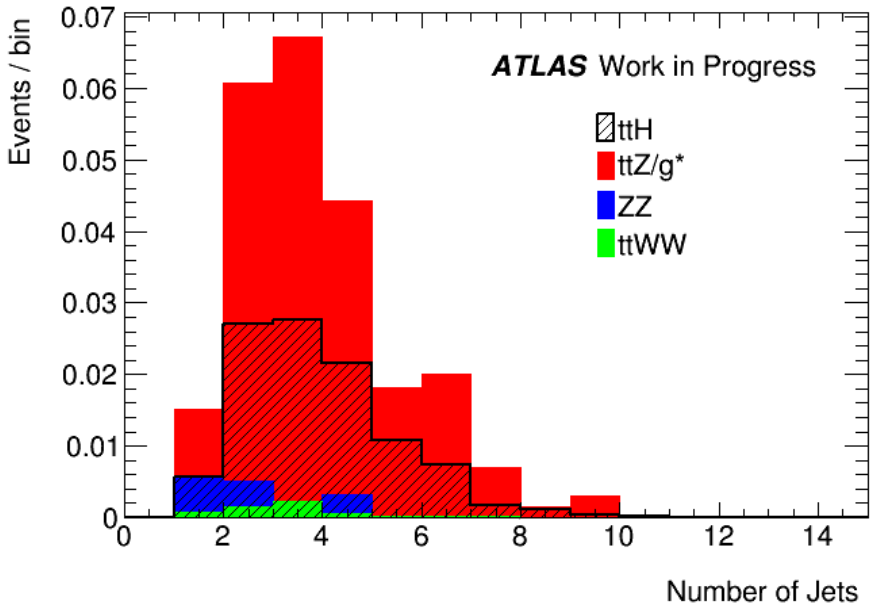




	ttH	Total **bkg**	ttZ/γ*	ttWW	ZZ	S/B	Exp. σ
Preselection	0.033 ± 0.003	0.019 ± 0.004	0.010 ± 0.003	0.003 ± 0.001	0.005 ± 0.002	1.734 ± 0.387	0.196 ± 0.021
$\Sigma_i q_i = 0$	0.033 ± 0.003	0.019 ± 0.004	0.010 ± 0.003	0.003 ± 0.001	0.005 ± 0.002	1.734 ± 0.387	0.196 ± 0.021
Trigger	0.032 ± 0.003	0.017 ± 0.004	0.010 ± 0.003	0.003 ± 0.001	0.003 ± 0.001	1.893 ± 0.448	0.201 ± 0.022
OSSF MII > 10 GeV	0.032 ± 0.003	0.017 ± 0.004	0.010 ± 0.003	0.003 ± 0.001	0.003 ± 0.001	1.893 ± 0.448	0.201 ± 0.022
# b-jets ≥ 1	$\mathbf{0.029 \pm 0.003}$	$\mathbf{0.012 \pm 0.003}$	0.009 ± 0.003	0.002 ± 0.001	0.000 ± 0.000	2.417 ± 0.708	$\mathbf{0.206 \pm 0.026}$

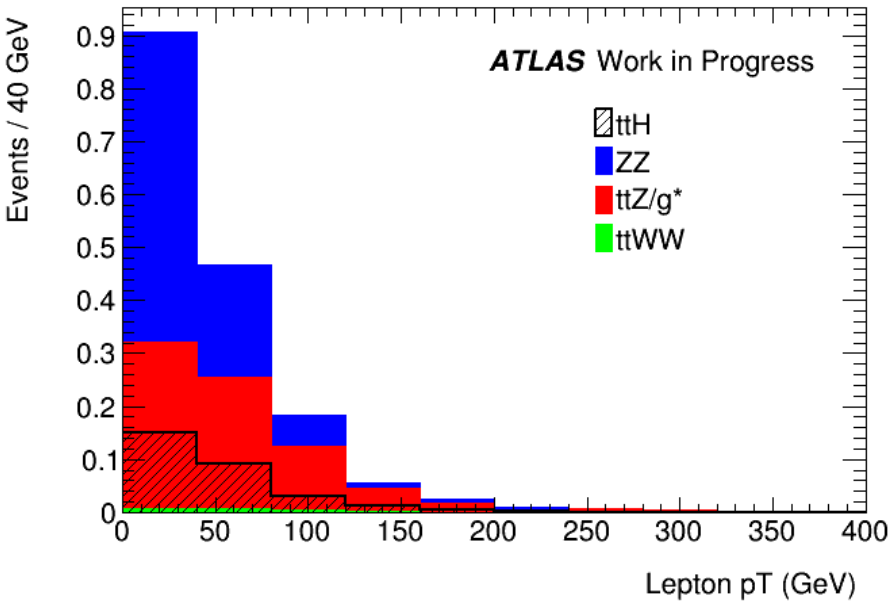
Z Enriched: $eee\mu$ and $e\mu\mu\mu$

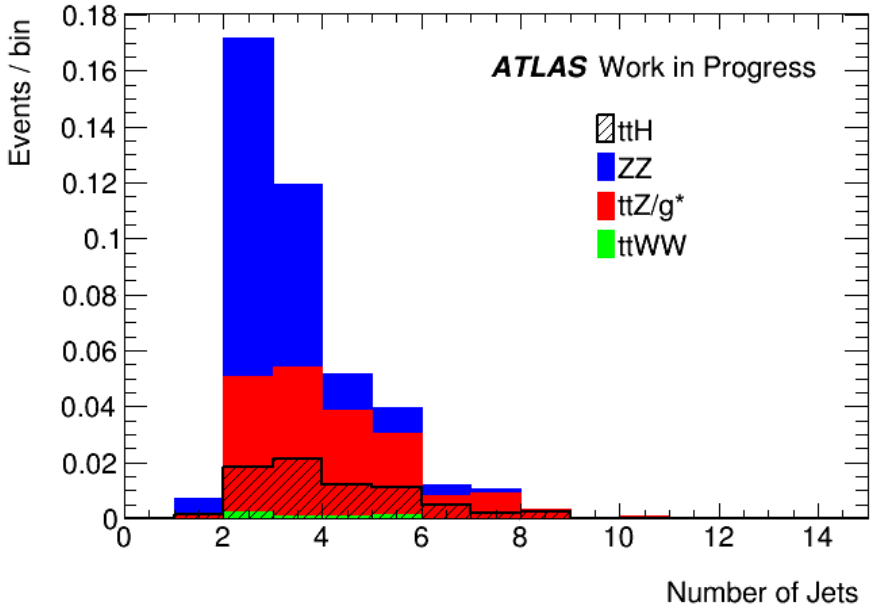




	ttH	Total **bkg**	ttZ/γ*	ttWW	ZZ	S/B	Exp. σ
Preselection	0.167 ± 0.007	3.842 ± 0.085	1.505 ± 0.039	0.008 ± 0.002	2.329 ± 0.076	0.044 ± 0.002	0.085 ± 0.004
$\Sigma_i q_i = 0$	0.167 ± 0.007	3.842 ± 0.085	1.505 ± 0.039	0.008 ± 0.002	2.329 ± 0.076	0.044 ± 0.002	0.085 ± 0.004
Trigger	0.164 ± 0.007	3.718 ± 0.084	1.497 ± 0.039	0.008 ± 0.002	2.213 ± 0.074	0.044 ± 0.002	0.085 ± 0.004
OSSF MII > 10 GeV	0.161 ± 0.007	3.639 ± 0.083	1.475 ± 0.039	0.008 ± 0.002	2.156 ± 0.073	0.044 ± 0.002	0.084 ± 0.004
# b-jets ≥ 1	0.140 ± 0.007	1.373 ± 0.039	1.307 ± 0.036	0.007 ± 0.001	0.059 ± 0.012	0.102 ± 0.006	0.118 ± 0.006
Z Veto	$\mathbf{0.103 \pm 0.005}$	$\mathbf{0.237 \pm 0.016}$	0.220 ± 0.015	0.006 ± 0.001	0.011 ± 0.005	0.437 ± 0.036	$\mathbf{0.199 \pm 0.011}$

ZZ Enriched: $eeee$, $\mu\mu\mu\mu$ and $e^{\pm}e^{\mp}\mu^{\pm}\mu^{\mp}$





	ttH	Total **bkg**	ttZ/γ*	ttWW	ZZ	S/B	Exp. σ
Preselection	0.132 ± 0.007	161.036 ± 0.566	1.528 ± 0.040	0.012 ± 0.002	159.497 ± 0.565	0.001 ± 0.000	0.010 ± 0.001
$\Sigma_i q_i = 0$	0.132 ± 0.007	161.036 ± 0.566	1.528 ± 0.040	0.012 ± 0.002	159.497 ± 0.565	0.001 ± 0.000	0.010 ± 0.001
Trigger	0.131 ± 0.007	156.804 ± 0.559	1.517 ± 0.039	0.012 ± 0.002	155.276 ± 0.557	0.001 ± 0.000	0.010 ± 0.001
OSSF Mll > 10 GeV	0.126 ± 0.007	144.233 ± 0.536	1.482 ± 0.039	0.011 ± 0.002	142.740 ± 0.534	0.001 ± 0.000	0.010 ± 0.001
# b-jets ≥ 1	0.112 ± 0.006	6.016 ± 0.103	1.307 ± 0.037	0.010 ± 0.002	4.699 ± 0.096	0.019 ± 0.001	0.046 ± 0.003
Z Veto	0.076 ± 0.005	0.562 ± 0.031	0.197 ± 0.014	0.006 ± 0.001	0.360 ± 0.027	0.135 ± 0.011	0.099 ± 0.007
$E_T^{miss} > 100 GeV$ OR # jets ≥ 1	$\mathbf{0.073 \pm 0.005}$	$\mathbf{0.417 \pm 0.025}$	0.192 ± 0.014	0.006 ± 0.001	0.220 ± 0.021	0.175 ± 0.015	$\mathbf{0.110 \pm 0.008}$

Cross Section Sensitivity Estimate **PRELIMINARY**

RooStats, 95% CL_S, p-values from toys

Systematics totally notional (30% on all cross sections)

Assumes a Higgs mass of 125 GeV

3 Lepton

	Expected Limit
Stats Only	3.5xSM
MC Stats	3.7xSM
30% X-Sec Syst	4.5xSM

4 Lepton

	Expected Limit
Stats Only	11.5xSM
MC Stats	11.9xSM
30% X-Sec Syst	13.4xSM

Combination 3 and 4 lepton channels: **4.3xSM**

Reference: Peter Onyisi

Summary and Outlook

Currently MC statistics limited; request more signal events

Finalize baseline selection for 4 lepton channel

Develop and study $ZZ \rightarrow 4l$ CR

Optimize lepton and jet selection

- Loosening lepton selection criteria will be the easiest way to increase our signal acceptance
- Will require communication with other ttH $\rightarrow$ leptons channels - number of selected leptons keeps SRs orthogonal

Ongoing effort to include hadronic taus

- Either as reconstructed hadronic taus or isolated tracks

At 14TeV the ttH cross section increases by a factor of $\sim$4

With $3000 fb^{-1}$ we have discovery potential in ttH $\rightarrow$ multileptons channel alone!

Acknowledgements

Pierre Savard

Bertrand Brelier

Peter Onyisi

Rustem Ospanov

Chris Lester

Santiago Batista

And many more!

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

https://indico.cern.ch/getFile.py/access?contribId=12&sessionId=2&resId=0&materialId=slides&confId=254268

https://indico.cern.ch/getFile.py/access?contribId=32&sessionId=2&resId=0&materialId=slides&confId=254268

Backup Slides

Object Selection

Electrons:

- Medium++, OQ
- $p_T > 10 GeV$
- $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$
- $p_T cone20/E_T < 0.05$
- If $E_T > 20 GeV$ then $E_T cone20/E_T < 0.10$ else $E_T cone20/E_T < 0.05$
- $|z_0 sin(\theta)| < 0.4 mm$
- $|d_0 sig| < 3 mm$

Jets:

- Loose jet cleaning
- $p_T > 20 GeV$

Muons:

- MuID tight
- MCP ID hit requirements
- $p_T > 10 GeV$
- $|\eta| < 2.5$
- $p_T cone20/p_T < 0.05$
- If $p_T > 20 GeV$ then $E_T cone20/p_T < 0.10$ else $E_T cone20/p_T < 0.05$
- $|z_0 sin(\theta)| < 1 mm$
- $|d_0 sig| < 3 mm$

+ Overlap removal

Cut Definitions

- Preselection: 4 good reconstructed electrons or muons
- $\Sigma_i q_i = 0$: Sum of the charges of all leptons is 0
- Triggers:
  - EF_mu24i_tight
  - EF_mu26_tight
  - EF_e24vhi_medium1
  - EF_e60_medium1
- OSSF Mll $>$ 10 GeV: Veto events with a same flavour opposite sign pair with an invariant mass $<$ 10 GeV
- # b-jets ≥ 1: Require at least one $p_T > 20 GeV$ jet with a $MV1$ 80% working point tag
- Z Veto: Veto events with a same flavour opposite sign pair with an invariant mass $81 GeV < Mll < 101 GeV$
- $E_T^{miss} > 100 GeV$ OR # jets ≥ 1: Veto event if it has $< 100 GeV$ E_T^{miss} and only 1 jet

Significance Definition

$$\sigma = \sqrt{2} * \sqrt{(S+B) * ln(1+S/B) - S}$$